SEMI-ANNUAL TECHNICAL SUMMARY

for the period ending 31 MARCH 1967

to

ADVANCED RESEARCH PROJECTS AGENCY

RESEARCH ON ELECTROMAGNETICS FOR PROJECT DEFENDER

ARPA Order No. 529 Program Code No. 5730

Report R-1295.4-67

for
Office of Naval Research
Contract Nonr-839 (38)

POLYTECHNIC INSTITUTE OF BROOKLYN

25

SEMI-ANNUAL TECHNICAL SUMMARY

for the period ending 31 MARCH 1967

to

ADVANCED RESEARCH PROJECTS AGENCY

RESEARCH ON ELECTROMAGNETICS FOR PROJECT DEFENDER

ARPA Order No. 529 *Program Code No. 5730*

Date of Contract: 1 February 1964

Expiration Date: 31 August 1968

Report
R-1295.4-67

for
Office of Naval Research
Contract Nonr-839(38)

Submitted by. Rudolf G. E. Hutter
Principal Investigator
Professor of Electrophysics

POLYTECHNIC INSTITUTE OF BROOKLYN

333 JAY STREET, BROOKLYN N. Y. 11201

ACKNOWLEDGEMENT

The work reported herein was sponsored by the Advanced Research Projects Agency, ARPA Order No. 529, Program Code No. 5730, and was monitored by the Office of Naval Research, Washington, D. C. under Contract No. Nonr-839(38).

ABSTRACT

This report contains a compilation of abstracts of papers which were either accepted for publication or were published. The papers are on the subjects of Plasmas, Fluid Dynamics and Electromagnetics. The work described was carried out under an ARPA contract, Order No. 529. This report also contains a listing of papers submitted to journals, lectures, internal reports and staff activities.

TABLE OF CONTENTS

I. INTRODUCTION

The Polytechnic Institute of Brooklyn is conducting a broad interdisciplinary theoretical and experimental research program in plasma aerodynamics, electromagnetic scattering theory and experimental plasma research applicable to both the immediate and long-range interests of the ARPA Ballistic Missile Defense Program. Emphasis will be placed on fluid dynamics, electromagnetic radiations and their interaction with media characteristic of the ballistic missile defense environment.

II. SUMMARY OF RESEARCH

A. PLASMAS

Cronson, H. M., "Microwave Heating by a Standing Wave in the Helium Afterglow", to be published in the Journal of Applied Physics, August 1967.

Spatial variations of electron temperature in the late helium afterglow in the pressure range 0.55 to 68 torr. are measured experimentally. The variations are due to the pressure of an applied standing wave at microwave frequencies. A normalized temperature profile is deduced from variations in the afterglow light quenching during a microwave pulse. Large temperature variations occur at higher pressures and smaller variations are seen at lower pressures. The observations are in good agreement with theory.

Freidberg, J. P., "Nonlinear Plasma Waves. Part I: Secular Behavior of Nonlinear Equations", published in the Physics of Fluids, January 1967, pp. 171-175.

A perturbation scheme is devised for investigating the periodic solutions of a nonlinear, second order, ordinary differential equation with an additional small nonlinear term. It is assumed that when the additional term vanishes the solution to the remaining zeroth order nonlinear equation is known. When this is the case, explicit expressions for the first order solution, and the first order correction to the dispersion relation are given in terms of the known zeroth order solution.

Freidberg, J. P., "Nonlinear Plasma Waves. Part II: Nonlinear Effects Near the Upper Hybrid Resonance", published in the Physics of Fluids, January 1967, pp. 176-183.

The problem of calculating the amount of energy which can be stored in a plasma near the upper hybrid resonance is treated by considering a macroscopic plasma model in which all nonlinear terms are maintained. For frequencies sufficiently close to the hybrid frequency, and for low temperatures, application of the traveling wave hypothesis reduces the macroscopic equations to an ordinary non-linear differential equation with an additional small nonlinear term. The solution of this equation, by the perturbation procedure described in Part I indicates that nonlinear effects (overtaking and trapping) become more important at lower energy levels as the frequency approaches the hybrid frequency. Explicit expressions are given for the maximum allowable stored energy at hybrid frequency in both a cold and warm plasma.

Freidberg, J. P., "Nonlinear Plasma Waves. Part III: Nonlinear Temperature Effects in the Electron-Ion Two Stream Instability", to be published in the Physics of Fluids.

The nonlinear interaction of two warm interpenetrating electron and ion streams is treated by investigating the traveling wave solutions to the two fluid macroscopic plasma equations. These equations are reduced to the form of a nonlinear differential equation with an additional small nonlinear term. Application of the perturbation procedure, described in Part I, leads to a nonlinear, amplitude dependent dispersion relation. An examination of this dispersion relation indicates that below a certain critical temperature, there is a range of wavenumbers where the two stream instability levels off before the onset of trapping. This range of wavenumbers decreases with increasing temperature and therefore is largest when the temperature is zero.

Friedman, H. W., "Non-Linear Asymptotic Analysis of the Positive Column", to be published in the Physics of Fluids.

The positive column of a slightly ionized gas discharge confined by cold, insulating walls is described by a set of non-linear fluid

equations. The inertia, space charge and collision terms are retained. A zeroth order solution uniformly convergent to the exact solution in both plasma and sheath regions is derived using asymptotic boundary layer analysis. The value of potential at the wall is calculated by means of kinetic model. It is found that the density at the wall can be a significant fraction of the value at the center and that it vanishes only in the low electron temperature limit. The original Bohm criterion is recovered as a necessary condition for sheath stability and is interpreted as (1) the velocity which asymptotically separates the plasma from the sheath and (2) the maximum ambipolar diffusion velocity.

Friedman, H. W., "Singularities of the Two-Fluid Plasma Equations and their Relation to Boundary Conditions", to be published in the Physics of Fluids.

The one dimensional fluid equations are used to describe a steady state, slightly ionized plasma confined by cold walls. The singularities of the complete two-fluid and approximate one-fluid equations are investigated and compared. It is found that the singularity in the one-fluid equations indicating a transition from plasma to sheath regions disappears in the two-fluid equations and therefore a smooth transition is predicted. Another singularity which is present in the two-fluid but not in the one-fluid equations is shown to be compatible if a constraint relation is satisfied at the singular point. In order that the two-fluid problem be well posed; (1) the boundary conditions are modified to insure that the constraint relation is satisfied and (2) a kinetic model is derived which uniquely specifies the wall potential for a given plasma configuration. The occurrence of a compatible singularity is shown to be analogous to the phenomenon of transonic flow in a convergent-divergent nozzle.

Koga, T., "The Hypothesis of EqualA Priori Probabilities in Kinetic Theory", presented at the 8th Annual Meeting of Americal Physical Society, Div. of Plasma Physics, Boston, Mass. in November 1966. Reprints available through U.S. Atomic Energy Documentation Center at Gmelin Institute.

The hypothesis of equal a priori probabilities is essential both in statistical mechanics and in kinetic theory. In the latter, the application of the hypothesis is conditional, as is exemplified by molar disorder in the presence of molecular order conceived by those authors such as Maxwell and Boltzmann in the last century. Previously the author asserted that the Bogoliubov-Born-Green-Kirkwood-Yvon (BBGKY) hierarchy is to be derived by course-graining the Liouville equation under a time-scale assumption. On the other hand, some authors seem to believe that no coarse-graining is necessary because the density of similar systems in the phase space is microscopically symmetric with respect to the interchange of phase coordinates between two similar particles. By the microscopic symmetry (unconditional application of the hypothesis of equal a priori probabilities), however, one must admit the same degeneracy in the states of those particles as in energy eigen-states of Bose-Einstein particles in a closely packed system. The assumption of microscopic symmetry is not plausible in view of the following: 1) A procedure of our experimental observation of kinetic theoretical processes is performed with respect to a single system along the time axis; 2) a finite change in the position and velocity of a particle cannot take place instantaneously; 3) similar particles are indistinguishable, but their states are distinguishable. These three reasons are relevant unconditionally for classical-mechanical systems and conditionally for quantum-mechanical systems. It is shown, in appendix B, that the derivation of the Boltzmann equation cannot be consistent from the BBGKY hierarchy based on the microscopic-symmetry assumption. In conclusion, the symmetry assumption is plausible in kinetic theory only conditionally and locally after coarse-graining operations. This conclusion is not trivial, particularly for ionized gases.

Koga, T., "Kinetic Equations for Plasmas", to be published in the Bulletin of the American Physical Society, April 1967.

Because of the time scale assumption necessary for its derivation, the Bogoliubov-Born-Green-Kirkwood-Yvon (BBGKY) hierarchy of equations is not applicable to systems consisting of charged particles,

except for special subsystems. A new class of equations governing the evolutions of charged particles is derived from the Liouville equation and is coarse-grained with respect to time and similar particles. In the zeroth approximation, there are two basic types of inter-particle interactions: One is of the Vlasov type and the other of the Boltzmann type characterizing interactions among nearest neighboring particles. In higher order approximations, mutual perturbations among those basic interactions result in secondary effects; for example, two nearest-neighboring particles exert a force of microscopic order to another particle. Depending on the ratio between the number of electrons and the number of ions in a real system, the simulating model varies. The main purpose of the paper is to present schemes of rational treatment, rather than to provide numerical results in detail for a particular system.

Sancer, M. I., "Bi-Orthogonal Expansions for the Linearized Anisotropic Multifluid Warm Plasma Equations", to be published in Radio Science, August 1967.

A bi-orthogonality relation is presented between the eigenfunctions of the operator representing the linearized anisotropic multifluid description of a cylindrical warm plasma and the eigenfunctions of the corresponding adjoint operator. This bi-orthogonality relation is used to describe the solution to the plasma equations when the plasma is excited by general sources, as well as to decompose a known solution into the appropriate eigenfunction expansion.

B. FLUID DYNAMICS

Lederman, S. and D. S. Wilson, "Microwave Resonant Cavity Measurement of Shock Produced Electron Precursors", J. AIAA, Vol. 5, No. 1, January 1967, pp. 70-77.

Microwave resonant cavities operated in the TM_{010} mode and constituting a part of the driven section of a pressure driven shock tube are used in this investigation. With argon as the driven gas (at a pressure of approximately 0.001 to 0.02 atm) and

hydrogen as the driver gas, the shock Mach number is varied over a range between 10.5 and 13.5. With the cavities operated in the S-band region, an electron density of the order of 5×10^{7} to 1×10^{10} el/cm^{3} can be measured. Using two cavities in tandem, tuned for the same resonant frequency and separated by a known distance, a measure of the precursor velocity is obtained. Several experiments are performed to determine the nature of the electron precursor, i.e., whether the precursor is caused by large scale diffusion of electrons from behind the incident shock or by radiation effects. It was found that electron precursor densities as high as 10^{8} el/cm^{3} were measured as far as 1/2 m in front of the shock, the electron precursor velocity is equal to the shock velocity, and the electron precursor in front of the shock is generated by radiation emitted from the ionized gas behind the incident shock.

Lederman, S., D. S. Wilson and E. F. Dawson, "The Application of a Langmuir Type Probe and Microwave Diagnostic Technique to Transient Ionized Flows", published in the IEEE Transactions on Aerospace and Electronic Systems, March 1967 (bearing title of "Langmuir Probe and Microwave Technique for Ionized Flows"). (Paper presented at 2nd International Congress on Instrumentation in Aerospace Simulation Facilities, Stanford University, Stanford, Calif. in August 1966).

Electron number densities were measured behind the incident shock wave in a pressure driven shock tube by a microwave resonant cavity technique and by electrostatic probes. The driven gas was air at initial pressures of .5 and 1mm Hg, and the shock Mach number was varied from 7 to 10. Electron neutral collision frequency was also determined by the microwave technique. The experimental measurements were compared with other measurements and with theory.

Schmidt, E. M. and R. J. Cresci, "Near Wake of a Slender Cone in Hypersonic Flow", to be published in AGARDograph, Proceedings of AGARD Specialists' Meeting on "Fluid Physics of Hypersonic Wakes" to be held in May 1967.

An experimental study has been performed to obtain the near wake characteristics of a sharp, 10° half angle cone at angle of attack in a hypersonic free stream environment. The tests were conducted at a free stream Reynolds number ($Re_D = 0.55 \times 10^6$) corresponding to a laminar near wake for the zero angle of attack condition. The inviscid flow field, including trailing shock configuration, and the viscous core behavior are compared to the corresponding data obtained at zero angle of attack. The major effects of the non-zero angle of attack are seen to occur in the mixing processes as indicated by centerline variations in static and stagnation pressure ratios. The recovery of these parameters to their free stream conditions for the cone at angle of attack appears to follow the turbulent, rather than the laminar, behavior for the corresponding cone at zero inclination.

Zinman, W.G., "Comment on Experimental Precursor Studies" AIAA Journal, Vol. 4, No. 11, November 1966.

It is shown how a two step process in which the first step is the absorption of a resonance quanta might account for the experimental result of Wilson and Lederman. They showed that the apparent photon mean free path is independent of the initial argon pressure in a shock tube.

C. ELECTROMAGNETICS

Berger, H. and J.W.E. Griemsmann, "Comments on 'Guided Waves in a Single Moving Medium' ", to be published in the Proceedings of IEEE.

This letter presents comments on a recent letter by Shiozawa which, in brief, are: (1) Du and Compton have published the solutions to the same problem, (2) Shiozawa presents an improper basis for the use of phase invariance and its consequences, and (3) Shiozawa's solution for $v = u$ is not valid.

Berger, H. and J. W. E. Griemsmann, "Guided Waves in Moving Dispersive Media. I - Non-Relativistic Velocities", to be published in the IEEE Transactions on Microwave Theory and Techniques.

This paper presents a theoretical examination of the influence of dispersive media on the time-harmonic, modal field structure of the electromagnetic waves in a cylindrical waveguide of arbitrary cross-section when the medium is in relative motion with respect to the waveguide walls. The modal field structure observed both in the reference frame F' attached to the medium, and in the reference frame F attached to the waveguide walls, are determined in closed form. The results presented for the modal fields observed in F are valid when the medium moves with a velocity that is small compared with $C_o = (\epsilon_o \mu_o)^{-1/2}$, and other specified reference velocities. Contact is made with the classical relativistic discussion of TEM waves in moving media by the introduction of the Fresnel drag coefficient. The theory is applied to the special cases of (a) non-dispersive moving media, and (b) a moving, low temperature, idealized plasma.

Berger, H. and J. W. E. Griemsmann, "Guided Waves in Moving Dispersive Media. II - Relativistic Velocities", to be published in the IEEE Transactions on Microwave Theory and Techniques.

The detailed modal field structure has been determined for electromagnetic waves propagating in a uniform, cylindrical, lossless waveguide of arbitrary cross-section filled with a moving media. The medium is assumed to be homogeneous, isotropic, and non-dissipative, but may be dispersive. The medium moves uniformly, with a constant speed v, parallel to the axis of the waveguide. The solutions obtained are exact, closed form functions of the space variables, time, the modal wave frequency and propagation factor, and hold for any value of the magnitude of v, from zero up to the speed of light in vacuum. The electromagnetic power flow in the waveguide is investigated, and it is demonstrated that it displays characteristics which differ considerably from those associated with the stationary medium case. The general theory is applied to several types of moving media including (1) nondispersive media, and (2) the idealized low temperature plasma.

Berger, H. and J. W. E. Griemsmann, "Moving Media Without Electromagnetic Drag", to be published in IEEE Transactions on Antennas and Propagation, July 1967.

It is demonstrated that the necessary and sufficient condition for a moving media not to exhibit a drag effect on electromagnetic waves propagating through that media is that the media display the dispersion generally associated with the cold, homogeneous, isotropic plasma. Because at sufficiently high frequencies all real media (in the linear approximation) display the above dispersion it follows that in those circumstances the drag effect is absent.

H. Berger and J. W. E. Griemsmann, "Poynting's Theorem for Moving Media", to be published in IEEE Transactions on Antennas and Propagation, May 1967.

Compton and Tai have published a generalization of Poynting's theorem for media moving with non-relativistic velocity, and have given physical interpretations for various terms of their resultant equation. In the present note Compton and Tai's result is transformed into another form which suggests a very different interpretation. The discussion includes relativistic velocities.

Felsen, L. B. and S. Rosenbaum, "Ray Optics for Radiation Problems in Anisotropic Regions with Boundaries. I. Line Source Excitation", to be published in Radio Science, August 1967.

Rigorous generic integral solutions for the fields radiated by phased line distributions of electric or magnetic currents in the presence of two arbitrarily anisotropic half-spaces are evaluated asymptotically by the saddle point technique. The resulting field constituents are shown to be interpretable invariantly as geometric-optical (incident, reflected and refracted) and diffracted (lateral wave) contributions. These fields are then derived <u>directly</u> from ray-optical arguments, thereby providing a justification for this procedure without intervention of the rigorous formulation. Because of the general validity of ray-optical concepts in connection with asymptotic solutions in the far zone, use of ray techniques is then advocated also for more complicated configurations which are not amenable to rigorous analysis.

Bertoni, H. L. and A. Hessel, "Ray Optics for Radiation Problems in Anisotropic Regions with Boundaries. II. Point Source Excitation", to be published in Radio Science, August 1967.

Based on a rigorous integral representation, the far fields radiated by an electromagnetic point source in the presence of a planar interface between two arbitrary homogeneous, lossless, anisotropic half-spaces are evaluated. An invariant ray-optical interpretation is given to the stationary point contributions (direct, reflected or transmitted rays) and to the branch curve contributions (lateral rays) to the asymptotic evaluation. The invariant form of the results highlights the local character of the ray-optical fields and permits one to postulate a generalization of the ray-optical method of analysis to the problem of reflection and transmission at a gently curved interface, which is generally not amenable to a rigorous analysis.

Felsen, L. B. and F. M. Labianca, "Radiation and Scattering Problems in Compressible Plasmas. I. Solutions by Ray Optics", published in Radio Science, Vol. 2 (New Series), No. 1, January 1967.

Ray-optical concepts are introduced for propagation of electromagnetic and electroacoustic waves in an unbounded compressible plasma, and are then applied to the analysis of radiation in the presence of plane or curved interfaces and obstacles. The method involves tracing of the electromagnetic and acoustic rays through the medium, due account being taken of coupling in source regions, at boundaries, and at scattering centers. The formulas for reflected, refracted, and diffracted fields derived in this manner are verified for special cases by the rigorous treatment in part II, thereby providing confidence in the validity of the procedure.

Labianca, F. M. and L. B. Felsen, "Radiation and Scattering Problems in Compressible Plasmas. II. Solutions of Boundary-Value Problems", published in Radio Science, Vol. 2 (New Series), No. 1, January 1967.

Different two-dimensional geometries involving bounded, homogeneous, isotropic, compressible plasma regions are considered,

and exact integral representations are developed for the electromagnetic and dynamical fields due to various excitations. Specifically, the geometries include plane and cylindrical interfaces, and also a perfectly conducting half plane embedded in the plasma. Asymptotic analysis of the exact solutions by the steepest-descent method leads to results which may be cast into a ray-optical form. It is shown that the geometric-optical and diffraction fields derived in this manner agree with those obtained in part I by direct application of ray-optical procedures. This conclusion lends substance to the validity of the ray-optical method and suggests its utility for even more general configurations which are not readily subjected to rigorous analysis.

Ott, E. and J. Shmoys, "Transient Aspects of Transition Radiation", to be published in the Quarterly of Applied Mathematics.

When a charged particle moving at uniform velocity crosses a boundary between two media with different electrical properties, a pulse of electromagnetic energy is emitted. This phenomenon is basically unlike either bremsstrahlung or the Cerenkov effect in that the charge will radiate even though it does not accelerate or move faster than the phase velocity of light in the medium.

Various theoretical[1] and experimental[2] aspects of transition radiation have recently been the subject of extensive study. It has been proposed that the effect might be useful in the generation of microwave power and as a diagnostic tool for the study of metals and plasmas.

It is clear that the effect is fundamentally a transient process. It is, therefore, surprising that the transient character of the fields has hardly received notice. Previous investigators have concentrated on determining the frequency spectrum of the radiation fields. We, on the other hand, will deal directly with the problem of finding the fields as a function of time.

In order to illustrate the essential characteristics of the processes involved, a specific problem will be considered. For the problem selected an exact closed form solution is obtained in a form amenable

to physical interpretation. It is found that before the time of impact the entire field may be represented in terms of an image picture, which is a generalization of the static case. Even after impact the image picture remains valid, but only in certain regions of space. At impact, a sudden burst of energy is liberated. This energy then propagates outward from the impact point in a manner to be discussed later. It is to be expected that the solution of the present problem will aid in the understanding of transition radiation in more complicated configurations, for which no closed form solution is available.

The method used to evaluate the transient is patterned after that given by Felsen[3]. A representation of the solution in terms of Fourier integrals will be obtained; these will be then reduced to such a form that they can be evaluated by inspection.

Sasiela, R. and J.P. Freidberg, "Utilization of the Refractive Index Surfaces to Evaluate Cerenkov Radiation in an Infinite Magnetoplasma", to be published in Radio Science, July 1967.

The utilization of refractive index surfaces in conjunction with the Clemmow, Mullaly, Allis (CMA) diagram greatly simplifies the determination of the regions of Cerenkov radiation and the types of waves emitted in a cold, collisionless, electron magnetoplasma. Also, the physical insight gained by this approach is used to expiain the qualitative behavior of the power spectrum.

Stalzer, H.J. and J. Shmoys, "Diffraction by a Cylinder in a Locally Uniaxial Medium with Azimuthal Optic Axis", to be published in Radio Science, August 1967.

An exact solution of Maxwell's equations is given for the problem of a magnetic line source parallel to the axis of a perfectly conducting cylinder in an inhomogeneous uniaxial medium of infinite extent. The inhomogeneity is due to the curvature of the lines of force of the static magnetic field responsible for the anisotropy of the medium. These lines of force are taken to be concentric with the cylinder. The exact solution is transformed, for frequencies above the plasma frequency and for large cylinder radius, to a more rapidly convergent form

which is given a geometric interpretation. The geometric interpretation can then be used to obtain approximate solutions when the magnetic field and the scatterer are more complicated and do not admit an exact solution of Maxwell's equations.

Ott, E. and J. Shmoys, "Transition Radiation and the Cerenkov Effect", to be published in the Quarterly of Applied Math.

III. ARPA-RELATED ACTIVITIES, LECTURES, VISITING PROFESSORS AND CONSULTANTS, PAPERS SUBMITTED TO OUTSIDE JOURNALS, AND INTERNAL REPORTS

A. ARPA-RELATED ACTIVITIES

Dean Martin H. Bloom, member of the Atomic and Molecular Physics Panel of the Institute for Defense Analyses

Dean Bloom is Associate Editor of the Journal of Ballistic Missile Defense Research, published by IDA for ARPA

Professor Rudolf Hutter has taken part informally in meetings and project reviews of the ARPA-ECM Electronic Components Subcommittee, headed by Col. Benjamin I. Hill of ARPA

Participation at outside meetings relevant to the program included the following talks:

a) 8th Annual Meeting, American Physical Society, Division of Plasma Physics, Boston, Mass., November 1966:

J. Freidberg, "Nonlinear Temperature Effects in the Two Stream Instability"

L. B. Felsen

R. G. E. Hutter

T. Koga, "The Symmetry Assumption of the Density of a System in the Phase Space the Hypothesis of Equal A Priori Probability in Kinetic Theory"

S. Lederman

E. Levi

J. Shmoys

K. Stuart, "Observations of Resistive Instabilities in a Toroidal Plasma"

D. S. Wilson

b) Defense Ionospheric Studies Symposium, San Juan, Puerto Rico, November 1966:

L. B. Felsen

c) Symposium on Plasma Turbulence, Institute for Defense Analyses, Arlington, Va., November 1966:

L. B. Felsen

R. G. E. Hutter

d) BMD Experimental Measurements Meeting, The Pentagon, Washington, D. C., November 1966:

M. H. Bloom, "Langmuir Probe Measurements"

e) Sperry Rand Research Center, Sudbury, Mass., January 1967:

H. Farber

R. G. E. Hutter

R. Pepper

f) Technical discussions at ARPA, Washington, D. C., March 1967:

M. H. Bloom

R. J. Cresci

B. LECTURES

There have been many formal seminars and informal discussion groups; a partial listing is given here:

October 1966:

Dr. H. T. Nagamatsu General Electric Research and Development Center	Hypersonic Boundary Layer Transition in the Mach Number Range 9.1-16

November 1966:

Dr. M. Baron Paul Weidlinger Consult. Engr.	Particle in Cell Method Studies and Their Application to High Velocity Impact Problems
Prof. W.R. Sears Cornell University	Another Boundary Layer Phenomenon in Magneto-Fluid-Dynamics
Dr. S. Przezdziecki Polish Academy of Sciences, Warsaw, and P.I.B.	A Method of Analysis of Propagation in Stratified Gyrotropic Media
Prof. C. Shulman C.C.N.Y.	Interaction Between Free Electrons and Light

December 1966:

Dr. C.C. Mow Aero-Astronautics Dept. The Rand Corporation	On the Transient Response of an Inclusion and Elastic Wave Scattering Phenomena
Prof. F.H. Abernathy Harvard University	Recent Developments in Bluff Body Wakes for Incompressible and Hypersonic Flows
Dr. M. Camac AVCO Everett Research Laboratory	Gas Dynamic Measurements with Electron Beams
Prof. P.A. Libby University of California San Diego	Some New Solutions in Laminar Boundary Layer Theory
Dr. R. Zirkind	Optical Diagnostics of Plasmas

January 1967:

Dr. W.S. Ament Naval Research Laboratory Washington, D.C.	How Valid is the Monte Carlo Method for Electromagnetic Multiple Scattering Problems?

February 1967:

Prof. L. Crocco Princeton University	Non-Linear Periodic Oscillations in Gaseous Systems
E. Ott	Transient Radiation in Inhomogeneous Plasmas
K. Stuart	The Toroidal Discharge

Prof. D. J. Rose Dept. of Nuclear Engrg. Mass. Inst. of Technology	Some Engineering Aspects of the Controlled Fusion Feasibility Problem
Dr. R. Monti University of Naples and P. I. B.	Thermodynamic Aspects of Multireacting Gaseous Systems

March 1967:

Dr. F. N. Frenkiel Applied Math. Lab. David Taylor Model Basin	Probability Distributions and Higher-Order Correlations in a Turbulent Field
Prof. C. K. Chu Columbia University	Some Numerical Experiments in MHD and Rarefied Gas Dynamics
Dr. A. Hessel	An Analysis of Plane Wave Scattering from a Modulated Corrugated Structure
Mr. E. Labuda Bell Laboratories	Electron Temperature and Density in a He Ne Discharge
Dr. M. P. Bachynski RCA Victor Labs., Ltd. Montreal, Ont., Canada	Laboratory Experiments on Electromagnetic Wave Interaction with Anisotropic Plasmas
Prof. R. Dorfman University of Maryland	Molecular Distribution and Transport Coefficients in a Moderately Dense Fluid

Polytechnic Institute of Brooklyn Symposium on Modern Optics

C. VISITING PROFESSORS AND CONSULTANTS

Dr. Toyoki Koga

Dr. Ilya Prigogine (University of Brussels)

Dr. Rudolfo Monti (University of Naples)

Dr. Nathan Marcuvitz (New York University)

D. PAPERS SUBMITTED TO OUTSIDE JOURNALS

Koga, T, "Kinetic Theoretical Bases of Dynamics of Gases", Jan. 1966, book manuscript submitted to Pergamon Press,

Lederman, S. and E. F. Dawson, "Application of a Microwave Technique to the Measurement of Electron Density and Ionization Time", submitted to Physics of Fluids

Berger, H. and J. W. E. Griemsmann, "The Influence of Moving Dispersive Media on Guided Waves", submitted to IEEE Trans. on MTT

Koga, T., "The Hypothesis of Equal A Priori Probabilities in Kinetic Theory", submitted to Review of Modern Physics

Koga, T., "Derivation of the Boltzmann Equation as a Test Case of Kinetic-Theoretical Schemes", submitted to Reviews of Modern Physics

Koga, T., "Symmetry of the Distribution Function of a System in Kinetic Theory", submitted to Physical Review Letters

E. INTERNAL REPORTS

Hoffert, Martin I "Nonequilibrium Structure of Hydromagnetic Gas-Ionizing Shock Fronts in Argon", PIBAL Report No. 1008, Polytechnic Institute of Brooklyn, Dept. of Aerospace Engineering and Applied Mechanics, February 1967

Coordinated by R. Hutter, "Research on Electromagnetics for Project DEFENDER", Semi-Annual Technical Summary for the period ending 30 September 1966, PIBMRI-1295.3-66

Berger, H. and J. W. E. Griemsmann, "The Influence of Moving Dispersive Media on Guided Waves", PIBMRI-1350-66, Polytech. Institute of Brooklyn, July 29, 1966

Berger, H. and J. W. E. Griemsmann, "Guided Waves in Dispersive Media Moving with Relativistic Velocity", PIBMRI-1351-66 Polytech. Institute of Brooklyn, July 29, 1966

Berger, H. and J. W. E. Griemsmann, "Relativistic Doppler Equations for Attenuated Waves", PIBMRI-1352-66 Polytech. Institute of Brooklyn

Cronson, H., "On Experimental Study of Microwave Heating in the Helium Afterglow", PIBMRI-1348-66 Polytech. Institute of Brooklyn

E. Ott and J. Shmoys, "Transient Aspects of Transition and Cerenkov Radiation". PIBMRI-1362-67 Polytech. Institute of Brooklyn, March 1967

E. Ott and J. Shmoys, "Transient Electromagnetic Wave Propagation in Lossless Isotropic Dispersional Media", PIBMRI-1361-67 Polytech. Institute of Brooklyn, March 1967

IV. PERSONNEL

M. H. Bloom	Professor Dean of Engineering Director, Gas Dynamics Research
R. J. Cresci	Professor
G. Dorman	Assistant Professor
H. Farber	Associate Professor
L. B. Felsen	Professor
J. W. E. Griemsmann	Professor
A. Hessel	Associate Professor
R. G. E. Hutter	Professor Principal Investigator
D. Jacenko	Research Associate
K. R. Jolls	Assistant Professor
T. Koga	Visiting Professor
S. Lederman	Associate Professor
L. Levey	Assistant Professor
E. Levi	Professor
D. Pepper	Research Associate
M. C. Peterson	Assistant Professor
S. Rosenbaum	Instructor
E. L. Rubin	Associate Professor
P. E. Serafim	Assistant Professor
P. M. Sforza	Assistant Professor
J. Shmoys	Associate Professor
N. Trentacoste	Research Assistant
D. S. Wilson	Assistant Professor
D. D. H. Yee	Assistant Professor

Advanced Research Projects
Agency
Attn: Dr. David C. Mann
The Pentagon
Washington, D.C. 20301

Advanced Research Projects
Agency
Attn: Lt. Col. R. M. Dowe, Jr.
The Pentagon
Washington, D. C. 20301

Advanced Research Projects
Agency
Attn: Mr. C. E. McLain
The Pentagon
Washington, D.C. 20301

Advanced Research Projects
Agency
Attn: Mr. F.A. Keother
The Pentagon
Washington, D.C. 20301

Advanced Research Projects
Agency
Attn: Dr. P J. Friel
The Pentagon
Washington, D. C. 20301

Advanced Research Projects
Agency
Attn: Dr. R. Zirkind
The Pentagon
Washington, D.C. 20301

Advanced Research Projects
Agency
Attn: Maj. H. Dickinson
The Pentagon
Washington, D.C. 20301

Aerojet-General Corporation
Attn: Technical Library
P.O. Box 296
Azusa, California 91703

Aeronutronic Division
Philco Corporation
Attn: Dr. H. Shenfield
Ford Road
Newport Beach, California 92600

Aerospace Corporation
Attn: Manager, Penetration Aids
2400 E. El Segundo Blvd.
El Segundo, California

Aerospace Corporation
Norton Air Force Base
Attn: Mr. William Barry
San Bernardino, Calif.

Commanding Officer
Office of Naval Research
Branch Office
207 West 24th Street
New York, N.Y. 10011

Air Force Cambridge Research
Laboratory
Attn: Scientific Library
CRRELR, Stop 29
L. G. Hanscom Field
Bedford, Mass.

Air Force Cambridge Research
Laboratory
Attn: Dr. Norman W. Rosenberg
L.G. Hanscom Field
Bedford, Mass.

Air Force Cambridge Research
Laboratory
Attn: Dr. K. Champion
L.G. Hanscom Field
Bedford, Mass.

Air Force Cambridge Research
Laboratory
Attn: Dr. A. T. Stair (CROR)
L.G. Hanscom Field
Bedford, Mass.

Air Force Office of Scientific
Research
Attn: Dr. M.C. Harrington
1400 Wilson Blvd.
Arlington, Virginia 22209

Air Force Office of Scientific
Research
Attn: Dr. D. L. Wennersten
1400 Wilson Blvd.
Arlington, Virginia 22209

Army Missile Command
Attn: AMCPM-ZER-R
Redstone Arsenal
Huntsville, Alabama 35808

Army Missile Command
Attn: AMSMI-RB
Redstone Arsenal
Huntsville, Alabama 35808

Army Missile Command
Attn: AMSMI-RNM
Redstone Arsenal
Huntsville, Alabama 35808

Army Research Office
Attn: Dr. Hermann Robl
Box C.M. Duke Station
Durham, N.C. 27706

Army Technical Intelligence
Agency
Attn: ORDLI
Arlington Hall Station
Arlington, Virginia 22314

Air Force Weapons Laboratory
Attn: Capt. David Sparks
Kirtland Air Force Base
Albuquerque, N.M.

Air Force Weapons Laboratory
Attn: Capt. William Whittaker
Kirtland Air Force Base
Albuquerque, N.M.

Applied Physics Laboratory
Johns Hopkins University
Attn: Dr. Felix Falls
8621 Georgia Avenue
Silver Springs, Md. 20910

Arecibo Ionospheric Observatory
Attn: Dr. W.E. Gordon, Dir.
Box 995
Arecibo, Puerto Rico

Australian Embassy
Attn: D. Barnsley, Defense
R. and E. Representative
2001 Connecticut Ave., NW
Washington, D.C. 20008

Avco-Everett Research Lab.
Attn: Technical Library
2385 Revere Beach Pkwy.
Everett, Mass. 02149

Avco-Everett Research Lab.
Attn: Mr. P. Rose
2385 Revere Beach Pkwy.
Everett, Mass. 02149

Avco-Research and Advanced
Development Div.
Attn: Mr. Harold Debolt
201 Lowell Street
Wilmington, Mass. 01887

Avco-Research and Advanced
Development Div.
Attn: Dr. A. Pallone
201 Lowell Street
Wilmington, Mass. 01887

Ballistics Research Laboratory
Attn: Dr. C.H. Murphy
Aberdeen Proving Ground, Md.
21005

Battelle Memorial Institute
Attn. Battelle-DEFENDER
505 King Avenue
Columbus, Ohio 43201

Bell Telephone Laboratories
Attn: Dr. C.W. Hoover
Whippany, N.J. 07981

Bendix Systems Division
Flight Sciences Department
Ann Arbor, Michigan

British Joint Mission
British Embassy
Attn: Mr. A. N. Mosses
Defense Research Staff
3100 Massachusetts Ave., NW
Washington, D. C. 20008

Brown University
Attn: Dr. John Ross
Department of Chemistry
Providence, Rhode Island
02912

Bureau of Naval Weapons
Special Projects Office
Attn: Commander Julian, SP-25
Munitions Bldg.
Washington, D.C. 20360

Canadian Armament Research
and Development Establish.
Attn: U.S. Army Liaison Officer
P.O. Box 1427
Quebec, P.Q., Canada

Air Force Cambridge Research
Laboratory
CRUB
Attn: Dr. K. Champion
Bedford, Mass.

Central Intelligence Agency
Attn: OCR Standard Distribution
2430 E St., NW
Washington, D.C. 20505

Chief of Naval Operations
Attn: OP-07TIO
Washington, D.C.

Dr. A. Hertzberg
Director, Aero. Lab.
University of Washington
Seattle, Wash. 98105

Cornell University
Nuclear Studies Laboratory
Attn: Dr. Edwin E. Salpeter
Ithaca, N. Y. 14850

Defense Atomic Support Agency
Attn: Dr. T. Taylor, Deputy
Director, Scientific
The Pentagon, 1 B 697
Washington, D. C.

Defense Atomic Support Agency
Attn: Dr. C. Blank
The Pentagon, 1 B 697
Washington, D.C.

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22314

50 copies

Defense Research Corporation
Attn: Dr. Bernard A. Lippman
P.O. Box 3587
Santa Barbara, California

U.S. Naval Postgraduate School
Attn: Tech. Reports Library
Monterey, Calif. 93900

General Applied Science Labs.
Attn: Library
Merrick and Stewart Avenues
Westbury, L.I., N.Y. 11590

General Applied Science Labs.
Attn: Dr. Lewis Feldman
Merrick and Stewart Avenues
Westbury, L.I., N.Y. 11590

RCA-Victor Co., Ltd.
Research Laboratories
Attn: Dr. A.I. Carswell
1001 Lenoir Street
Montreal 30, Canada

General Dynamics Corporation
Convair Division
Attn: Mr. K.G. Blair
Chief Librarian
P.O. Box 166
San Diego, California 92112

Commanding Officer
U.S. Naval Weapons Lab.
Dahlgren, Virginia 22448

General Electric Co., MSVD
Document Library
Reentry Physics Library Unit
Attn: Mgr.-MSVD Library 3446
3198 Chestnut Street
Philadelphia, Pa.

General Electric Research Lab.
Attn: Dr. George C. Baldwin
(General Engineering Lab.)
Schenectady, New York 12301

General Electric Space Sciences
Laboratory
Attn: Dr. T. Reithoff
Valley Forge Space Tech. Ctr.
P.O. Box 8555
Valley Forge, Pennsylvania

General Electric Tempo
Attn: Dr. R. Hendrick
Santa Barbara, California

General Motors
Defense Research Laboratory
Attn: Mr. C.M. Shaar
Box T
Santa Barbara, California 93102

Geophysics Corp. of America
Burlington Road
Bedford, Mass.

Harvard University
Chemistry Department
Attn: Dr. Dudley R. Hershbach
Cambridge, Mass. 02138

Headquarters BSD (AFSC)
Air Force Unit Post Office
Attn: BSRVD
Los Angeles, Calif. 90045

Heliodyne Corporation
Attn: Dr. Saul Feldman
7810 Burnet Avenue
Van Nuys, Calif. 91405

Dr. W. Culver
International Business Machines
326 E. Montgomery Avenue
Rockville, Maryland

Institute for Defense Analyses
Attn: Dr. A. Hochstim
400 Army-Navy Drive
Arlington, Virginia 22202
2 copies

Institute for Defense Analyses
Attn: Dr. D. Katcher
JASON Library
400 Army-Navy Drive
Arlington, Virginia 22202

Institute for Defense Analyses
Attn: Dr. J. Menkes
400 Army-Navy Drive
Arlington, Virginia 22202

Institute for Defense Analyses
Attn: Dr. H. Wolfhard
400 Army-Navy Drive
Arlington, Virginia 22202

Institute for Molecular Physics
Attn: Dr. Edward A. Mason
University of Maryland
College Park, Maryland

Joint Inst. for Lab. Astrophysics
NBS, University of Colorado
Attn: Dr. Lewis Branscomb
1511 University Avenue
Boulder, Colorado

Jet Propulsion Laboratory
Attn: Library
4800 Oak Grove Drive
Pasadena, California 91103

Kansas State University
Attn: Prof. Basil Curnutte
Physics Department
Manhattan, Kansas

Lincoln Laboratory, M.I.T.
Attn: Dr. M. Balser
P.O. Box 73
Lexington, Mass. 02173

Lockheed Missiles and Space Co.
Attn: Dr. R. Myerott
3251 Hanover Street
Palo Alto, California

Lockheed Missiles and Space Co.
Attn: Dr. Leon Fisher
3251 Hanover Street
Palo Alto, California

Monsanto Research Corporation
Dayton Laboratory
Attn: Dr. J. W. Butler
1515 Nicholas Road
P.O. Box 8, Station B
Dayton, Ohio

Naval Ordnance Laboratory
Attn: Librarian
White Oak
Silver Spring, Maryland
20910

Naval Research Laboratory
Attn: Dr. Alan Kolb, Code 7470
Washington, D.C. 20390

Naval Research Laboratory
Attn: Code 2027
Washington, D.C. 20390
6 copies

National Aeronautics and Space Administration
Attn: Applied Materials and Physics Div., Code SL
Langley Research Center
Hampton, Virginia 23365

National Aeronautics and Space Administration
Attn: Mail Stop 213
Langley Research Center
Hampton, Virginia 23365

Radio Corporation of America
Missile and Surface Radar Div.
Moorestown, N. J. 08057

Director
Naval Research Laboratory
Washington, D. C. 20390

Attn: Dr. R. M. Page

National Bureau of Standards
Attn: Dr. Karl G. Kessler, Chief
Atomic Physics Div.
Washington, D.C. 20234

National Bureau of Standards
Attn: Dr. M.B. Wallenstein
Chief, Physical Chem. Div.
Washington, D.C. 20234

National Bureau of Standards
Attn: Dr. Kurt E. Shuler
Washington, D.C. 20234

National Bureau of Standards
Attn: Dr. E.L. Brady
National Standard Reference Data Center
Washington, D.C. 20234

New York University
Attn: Dr. Benjamin Bederson
Physics Department
University Heights
New York, N.Y. 10453

New York University
Attn: Dr. Sidney Borowitz
Physics Department
University Heights
New York, N.Y. 10453

Oak Ridge National Laboratory
Attn: Dr. S. Datz
P.O. Box X
Oak Ridge, Tenn.

Office of Naval Research
Department of the Navy
Attn: Dr. S.G. Reed, Jr.
Science Director
Washington, D.C. 20360

Office of Naval Research
Department of the Navy
Attn: Dr. J.H. Shenk
Materials Science Div.
Washington, D.C. 20360

Office of Naval Research
Department of the Navy
Attn: Dr. W.E. Wright
Physical Sciences Div
Washington, D.C. 20360

Office of Naval Research
Department of the Navy
Attn: Dr. F.T. Byrne
Physics Section
Washington, D.C. 20360

Polytechnic Institute of Brookl
Attn: Mr. Jerome Fox
Research Office
333 Jay Street
Brooklyn, N. Y. 11201

Queen's University of Belfast
Attn: Professor D.R. Bates
Department of Applied Math.
Belfast 7, Northern Ireland, UK

The Rand Corporation
Attn: Library
1700 Main Street
Santa Monica, California
90401

The Rand Corporation
Attn: Dr. R. Hundley
1700 Main Street
Santa Monica, California
90401

The Rand Corporation
Attn: Dr. Forrest R. Gilmore
1700 Main Street
Santa Monica, California
90401

The Rand Corporation
Attn: Dr. Robert E. LeLevier
1700 Main Street
Santa Monica, California
90401

Rocketdyne Division
North American Aviation, Inc.
Attn: Dr. S. A. Golden
Physics Group
6633 Canoga Avenue
Canoga Park, Calif. 91304

Sperry Rand Research Center
Attn: Dr. Philip M. Stone
North Road (Route 117)
Sudbury, Mass.

Space Technology Laboratories
Attn: Dr. L. Hromas
1 Space Park
Redondo Beach, California
90200

Stanford Research Institute
Attn: Dr. C. J. Cook, Director
Chemical Physics Div.
333 Ravenswood Avenue
Menlo Park, California 94025

Chief of Naval Research
Department of the Navy
Code 427
Washington, D. C. 20360

Commanding Officer
U. S. Naval Electronics Lab.
San Diego, Calif. 92152

Commanding Officer and Dir.
U. S. Naval Training Device
Center
Attn: Technical Library
Orlando, Florida 32813

Stanford Research Institute
Attn: Dr. Carson Flammer, Mgr.
Mathematical Div.
333 Ravenswood Avenue
Menlo Park, California 94025

United Aircraft Corporation
Research Laboratories
Attn: Dr. Russell G. Meyerand
East Hartford, Conn. 06118

University of Alabama
Attn: Dr. Erich Rodgers
Physics Department
P. O. Box 1921
University, Alabama 48106

University of California
Attn: Prof. Kenneth Watson
Physics Department
Berkeley, California 94704

University of California
Lawrence Radiation Laboratory
Attn: Dr. Marvin Mittleman
Box 808
Livermore, California 94551

University of California
Attn: Dr. Herbert P. Broida
Department of Physics
Santa Barbara, California

Dr. Keith A. Brueckner
University of California
San Diego
P. O. Box 109
La Jolla, Calif. 92038

University of Chicago
Attn: Dr. John Light
Chemistry Department
Chicago, Illinois

Commanding Officer
Naval Ordnance Test Station
China Lake, Calif. 93357

Commanding Officer
U. S. Naval Avionics Facility
Indianapolis, Indiana

University of Chicago
Attn: Prof. C. C. J. Roothaan
Department of Physics
Chicago, Ill.

University of Florida
Attn: Dr. Alex Green
Physics Department
Gainesville, Florida 32603

University of Michigan
Attn: Dr. R. Bernstein
Chemistry Department
Ann Arbor, Michigan 48106

University of Michigan
Attn: Dr. Otto LaPorte
Physics Department
Ann Arbor, Michigan 48106

University of Minnesota
Attn: Prof. H. J. Oskam
Department of Electrical
Engineering
Institute of Technology
Minneapolis 14, Minn. 55414

University of Pittsburgh
Attn: Professor Wade Fite
Pittsburgh, Pa. 15214

University of Southern Calif.
Attn: Prof. G. L. Weissler
Department of Physics
University Park
Los Angeles, Calif. 90007

Westinghouse Electric Corp.
Attn: Dr. A. Phelps
Research Physicists
Research Laboratories
Pittsburgh 35, Pa.

Commanding Officer
Naval Ordnance Test Station
Corona, Calif. 91720

Commanding Officer
Office of Naval Research
Branch Office
Box 39, Fleet Post Office
New York, N. Y. 09510

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) Polytechnic Institute of Brooklyn 333 Jay Street Brooklyn, New York 11201	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

3 REPORT TITLE

Research on Electromagnetics for Project DEFENDER

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Semi-Annual Technical Summary for period ending 31 March 1967

5 AUTHOR(S) (Last name, first name, initial)

Principal Investigator: Rudolf G. E. Hutter

6 REPORT DATE	7a TOTAL NO OF PAGES	7b. NO OF REFS
30 June 1967	28	0

8a CONTRACT OR GRANT NO Nonr-839(38)	9a ORIGINATOR'S REPORT NUMBER(S) PIBMRI-1295.4-67
b PROJECT NO ARPA Order No. 529	
c Program Code No. 5730	9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d	

10 AVAILABILITY LIMITATION NOTICES

Qualified requestors may obtain copies of this report from DDC. Other persons or organizations should apply to the Clearinghouse for Federal Scientific and Technical Information (CFSTI), Sills Bldg., 5285 Pt. Royal Road, Springfield, Va.

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
	Advanced Research Projects Agency and Office of Naval Research, Washington, DC

13 ABSTRACT

This report contains a compilation of abstracts of papers ~~which were~~ either accepted for publication or were published. The papers are on the subjects of Plasmas, Fluid Dynamics and Electromagnetics. The work described was carried out under an ARPA contract, Order No. 529. This report also contains a listing of papers submitted to journals, lectures, internal reports and staff activities.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Microwave heating						
Nonlinear plasma waves						
Plasma sheath						
Kinetic theory						
Precursor						
Langmuir probe						
Near wake						
Shock waves						
Instabilities						
Moving media						
Ray optics						
Scattering						
Transition radiation						
Cerenkov radiation						
Electron density, microwave measurement						

INSTRUCTIONS

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. **AVAILABILITY/LIMITATION NOTICES:** Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.